International Environmental Modelling and Software Society (iEMSs)
2010 International Congress on Environmental Modelling and Software
Modelling for Environment's Sake, Fifth Biennial Meeting, Ottawa, Canada
David A. Swayne, Wanhong Yang, A. A. Voinov, A. Rizzoli, T. Filatova (Eds.)
http://www.iemss.org/iemss2010/index.php?n=Main.Proceedings

Risk assessment and decision support tools for the integrated evaluation of climate change impacts on coastal zones

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Abstract: Nowadays there is new and stronger evidence that sea level rise, increased storminess and coastal erosion as a consequence of global warming are likely to have profound impacts on coastal communities and ecosystems. Regional Risk Assessment (RRA) is an interdisciplinary approach to evaluate and rank potential impacts, targets and areas at risk from climate change hazards. Within the Euro-Mediterranean Centre for Climate Change (CMCC) a RRA methodology was developed to assess impacts of climate change at the regional scale and to assist coastal communities in planning adaptation measures. The proposed methodology integrates the output of downscaled climate, circulation, morphodynamic and biogeochemical models to represent the exposure to climate change hazards (e.g., flooding, erosion, water quality changes) and includes the analysis of site-specific environmental and socio-economic vulnerability of coastal systems to the impact of hazards (e.g., land use, geomorphology, vegetation cover, population density). It is implemented as part of a GIS-based DEcision support SYstem for COastal climate change impact assessment (DESYCO), that will provide information about downscaled climate change scenarios and regional/local vulnerabilities and risks, and will guide decision-makers in planning appropriate adaptation strategies. The main components of the DSS and of the RRA methodology and the preliminary results of their application to the coastal area of the Northern Adriatic Sea (Italy) are here presented and discussed.

***Keywords**:* Risk Assessment, Climate Change, Decision Support Systems, GIS

1. INTRODUCTION

Nowadays there is new and stronger evidence that global warming is likely to have profound impacts on coastal communities and ecosystems [IPCC, 2007]. Accelerated sea level rise, increased storminess, changes in water quality and coastal erosion as a consequence of global warming, are projected to pose increasing threats to coastal population, infrastructure, beaches, wetlands, and ecosystems. Beyond this, coastal zones represent an irreplaceable and fragile ecological, economic and social resource. Being the result of a dynamic, unpredictable and interdependent set of subsystems, they are under increasing pressure leading to coastal resources depletion, conflicts between use, and natural ecosystems degradation [COM(2007) 308 final]. Climate change impacts affecting coastal communities and ecosystems are greatly influenced by regional geographical features, climate and socio-economic conditions. Impact studies should therefore be performed at the local/regional level, taking into account downscaled climate change scenarios and site-specific coastal vulnerability determined by environmental and socio-economic conditions. Accordingly, it is necessary to develop innovative interdisciplinary approaches and tools to effectively cope with climate related risks and support decision making processes at the regional to local level.

Decision Support Systems (DSSs) are computer based information system designed to support unstructured problem solving, decision making, and decision implementation [Le Blanc, 1991]. In particular, DSSs are considered useful tools to cope with climate change related issues and support decision makers in a sustainable management of natural resources and in the definition of mitigation and adaptation measures. These tools can be characterized by a framework and a structure. The first one refers to the assessment and management issues to which the DSS responds and for which it offers a specific functionalities while the structure describes the main components of the system in terms of database, model and graphical interface [Agostini et al, 2009].

As stated by Janssen [1992], a DSS is expected to support rather than replace judgement of decision makers, to assist them and to improve effectiveness of decision making rather than its efficiency. There are different types of DSS, such as spatial DSS and environmental DSS. As stated by Densham [1991], spatial DSS are "explicitly designed to provide the user with a decision-making environment that enables the analysis of geographical information to be carried out in a flexible manner". An environmental DSS consists of various coupled environmental models, databases and assessment tools, which are integrated under a graphical user interface, often realized by using spatial data management functionalities provided by geographical information systems (GIS) [Matthies, 2005]. A DSS applied in a coastal zone management perspective need to be at the same time spatial and environmental.

With the main aim to prioritize potential impacts, targets and areas at risk from climate change on coastal zones at the regional scale, a spatial and environmental DEcision support SYstem for COastal climate change impact assessment (DESYCO), was developed within the Euro-Mediterranean Centre for Climate Change (CMCC, www.cmcc.it) and applied to the coast of the North Adriatic Sea in Italy. The core of the DESYCO is a Regional Risk Assessment methodology (RRA) that allow to estimate the relative risks in the considered region, compare different impacts and stressors, rank targets and exposure units at risk from climate change, in order to support decision-makers in the design of adaptation strategies.
In this paper, after a brief description of the CMCC centre and of the case study area, the main objectives and functionalities of the DESYCO and of the RRA methodology will be presented and discussed.

2. THE CMCC CENTRE

The Euro-Mediterranean Centre for Climate Change (CMCC, www.cmcc.it) is a national (Italian) research centre devoted to the study of climate change and its impacts, focusing on the Mediterranean region. The CMCC make use of a new supercomputing centre that was inaugurated in January 2009. It is composed of two last-generation supercomputers that allow to run numerical models of different complexity and realism, in order to study the natural variability of the climate and the climatic changes, with a particular emphasis on the European and Mediterranean region. The modelling outputs of CMCC are used to assess climate change impacts on the economy, agriculture, on the marine and terrestrial ecosystems, on coastal areas and on human health. Within CMCC the development of a DEcision support SYstem for COastal climate change impact assessment (DESYCO) is being coordinated by Venice Research Consortium, whose partners for this project are the National Research Council, the Tidal Forecast and Information Centre of the Venice City Council and the Ca' Foscari University of Venice.

3. THE CASE STUDY AREA

The area considered in the Case study involves the coastal zone of Veneto and Friuli-Venezia Giulia regions, bordering the North Adriatic Sea with a overall length of about 286 km (Fig. 1).

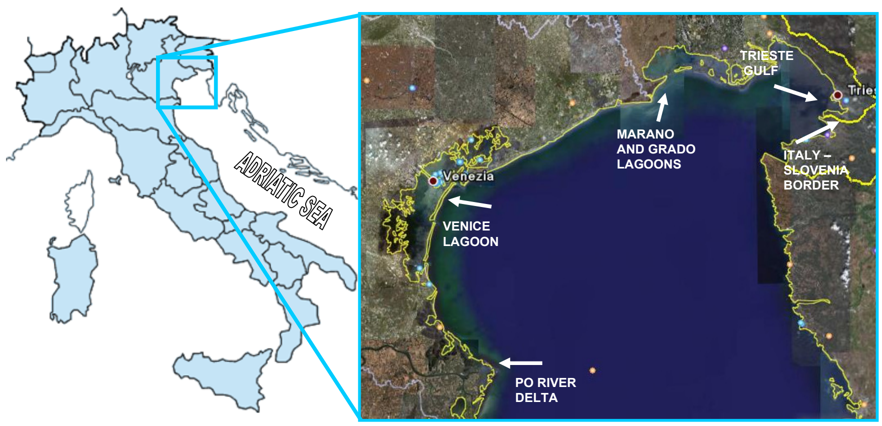

Figure 1: The case study area: the Northern Adriatic Sea and the coast of the Veneto and Friuli Venezia Giulia regions (Italy). (Adapted from google maps: maps.google.it).

The coast of the case study area runs along the Adriatic Sea from the national border between Italy and Slovenia to the mouth of the southern tributary of the Po Delta system (i.e., Po di Goro). From north east to south west, between the Slovenian border and the Timavo river mouth, the coast is high and rocky with few narrow beaches. In the rocky coast there can be found the gulf of Trieste and several bays (e.g., Sistiana Bay). Moving southwards, from Monfalcone to the Po river delta the coast consists of low sedimentary shores. The overall continuity of the coast is interrupted by several river outlets (e.g., Tagliamento, Isonzo, Livenza, Piave, Brenta, Adige and Po) and lagoons (i.e., Marano, Grado and Venice lagoons and the lagoons of the Po river Delta). From a morphological point of view the sedimentary shores of the case study area include straight littoral coasts, lagoonal barrier islands, spits, river outlets and salt marshes. The main coastal activities of the case study area are petrochemical industry, tourism, fishing, seaport/ port activities and ship traffics. On the whole, the Northern Adriatic Sea coast, comprises a very precarious coastal environment subject to continuous morphological changes that can be appreciable even over short geological time scales [Gambolati and Teatini, 2002]. Moreover, erosion is still active in many areas both on the coastal sea floor and on the beach since the beginning of the 20th century and especially after 1960 [Bondesan et al., 1995]. Many areas, particularly around the Po River Delta, are also located below the mean sea level and affected by natural or man-induced subsidence [Pirazzoli, 2005]. Furthermore, the municipality of Venice has been experiencing an increase of high tide events with consequent flooding of the city (www.comune.venezia.it). In the Mediterranean Sea, rates of sea level rise for the three longest tide-gauge stations ranged from 1,1 mm/yr to 1,3 mm/yr [Tsimplis and Spencer, 1997]. However, spatially the change is not uniform and in the North Adriatic sea the observed sea level rate can vary from 1,2 mm/yr in Trieste to 2,5 mm/yr in Venice [Antonioli and Silenzi, 2007]. Therefore, climate change and sea level rise is a prominent issue for the case study area both considering the vulnerability of fragile ecosystems such as coastal lagoons, and the concentration of cultural and socio-economic values. Accordingly, DESYCO and the RRA methodology proposed in this paper are innovative tools to characterize climate change related hazards, vulnerabilities and risks in the case study area and support the definition of preventive adaptation strategies.

4. THE REGIONAL RISK ASSESSMENT METHODOLOGY AND THE DECISION SUPPORT SYSTEM FOR COASTAL CLIMATE CHANGE IMPACT ASSESSMENT (DESYCO).

The proposed RRA methodology for the estimation of climate change impacts on coastal systems is intended to be an aid for national and regional authorities in examining the possible consequences associated with uncertain future climate and prioritize adaptation measures. Traditionally, RRA aims at providing a quantitative and systematic way to estimate and compare the impacts of environmental problems that affect large geographic areas [Hunsaker et al., 1990]. In more detail, the RRA is defined as a risk assessment procedure which considers the presence of multiple habitats, multiple sources releasing a multiplicity of stressors impacting multiple endpoints [Landis, 2005]. Accordingly, the RRA approach concerns the use of MultiCriteria Decision Analysis (MCDA) in order to estimate the relative risks in the considered region, compare different impacts and stressors, rank targets and exposure units at risk, and select those risks that need to be investigated more thoroughly.

According to Torresan et al. [2007], the RRA methodology is part of a more comprehensive framework for climate change impact and risk assessment in coastal areas at the regional scale. The framework integrates tools and methodologies for the identification of potential climate change impacts and the assessment of bio-physical and socio-economic coastal vulnerability, in order to rank relative risks in the considered region. For this purpose, the framework structure is composed of 3 main phases: the <u>Scenarios construction</u> phase which is aimed at the definition of future climate scenarios for the examined case study area at the regional scale, the <u>Integrated impact and risk assessment phase</u> which is aimed at the prioritization of impacts, targets and affected areas at the regional scale, and the <u>Risk and impact management phase</u> which is devoted to support adaptation strategies for the reduction of the risks and impacts in the coastal zone, according to ICZM principles. Within the aforementioned framework, the main output of the RRA is the development of GIS-based maps. RRA maps include exposure maps representing the exposure to climatic changes against which a system operates (e.g., inundation level) and vulnerability maps representing the spatial distribution of environmental and socio-economic vulnerability factors. These maps allow the visualization and prioritization of impact areas and vulnerable coastal receptors, the identification of more sensitive areas in the coastal territory, and the location of more suitable areas for human settlements, infrastructures and economic activities. Moreover they allow an easy and flexible visualization of vulnerabilities and risks for stakeholders and decision makers.

In order to represent potentially significant hazard scenarios at the regional scale and build climate change Exposure maps to be used in the risk assessment, a chain of models was set up for the study area of the North Adriatic Sea. The models chain includes different types of numerical models simulating relevant circulation and morphodynamic processes that may influence climate change impacts on coastal areas at different spatial scales. Starting from global and regional circulation models representing the main climate dynamics and covering large spatial domains (i.e., from the global to the sub-continental scale), the chain of models includes a suite of higher resolution models able to simulate ocean dynamics and circulation, biogeochemical and fate and transport processes in coastal waters, with a spatial domain ranging from the sub-national/regional to the local scale. Moreover, the suite of models applied to the North Adriatic Sea includes a regional fugacity model to analyse coarse fate and transport processes of persistent organic pollutants in the Adriatic Sea. Models included in the models chain have been made available by partners involved in the CMCC project that are the National Institute for Geophysics and Vulcanology, the Marine Science Institute of the Italian National Research Council and the University Ca' Foscari of Venice. Within DESYCO the proposed model chain is forced by the IPCC SRES scenario A1B [Nakićenović et al., 2000] and allows the investigation of different climate change impacts including regional inundation processes and increased storm surge flooding due to global sea level rise, erosion processes due to bottom stress, wind, waves and tide, water quality variations due to the concentration of nutrients and contaminants. The outputs of the model chain are called hazard metrics (HM) that are used in the RRA equations for the construction of GIS-based exposure maps that identify and classify areas potentially subject to the examined impacts and provide spatially resolved information about the intensity of potential hazards linked to climate change in the case study area.

The characterization of the territorial vulnerability and the construction of vulnerability maps involves the development and application of a range of vulnerability indicators and indexes, representing the sensitivity of the coastal communities, systems or assets to the damaging effects of climate change hazards [Torresan et al. 2008]. Consequently, in order to identify site-specific targets and areas vulnerable to potential climate change impacts in the considered region, a subset of vulnerability indicators was defined and applied to the coasts of the North Adriatic Sea.

According to Voice et al. [2006] and the Australian society of Coastal Zone Management (www.ozcoasts.org.au), the subset is referred to different coastal receptors (e.g., beaches and dunes, wetlands, hydrological systems, protected areas or fisheries and aquaculture), and is related to different climate change impacts (e.g., erosion, inundation, water quality variations). Moreover, it encompass a wide range of biogeophysical and socio-economic factors representing the coastal vulnerability to climate change at the regional scale, and was selected taking into account the availability of environmental and territorial data for the study area.

Available data were provided by various public institutions in graphic format or database, and include a 5 m Digital Elevation Model (DEM) supplied by Veneto Region and a 10 m DEM by Friuli Venezia Giulia Region, the digital Corine Land Cover (CLC2000) database (e.g., wetlands, vegetation cover, hydrological systems, dunes) (http://www.clc2000.sinanet.apat.it/cartanetclc2000/clc2000/prodotti.asp), a list of Natura 2000 sites (i.e., ZPS and SIC areas) supplied by regional authorities, coastal data included in the geographic coastal information system(e.g., coastal morphology, sediment budget, artificial protections) implemented by the Italian Environmental Protection Agency (APAT, now called ISPRA) (http://www.mais.sinanet.apat.it), technical regional maps supplied by the Veneto and Friuli Regions (www.regione.veneto.it /Ambiente+e+Territorio/; www.regione.fvg.it/rafvg/territorioambiente), and administrative boundaries of coastal municipalities and provinces furnished by regional authorities.

Within the RRA, vulnerability indicators are classified in three main categories of factors: Susceptibility Factors (SF), Value Factors (VF) and Pathway Factors (PF). SF determine the degree to which a receptor is affected, either adversely or beneficially, by climate-related stimuli. They denote the dose-response relationship between the exposure of a receptor to climate stimuli and the resulting effects. VF identify relevant environmental and socio-economic values of the receptors that need to be preserved for the interest of the community (e.g., land use, fishing areas, etc.). PF are physical characteristics of the receptors determining the possibility of contact with climate change hazards and therefore potential exposure areas (e.g., elevation, distance from coastline).

In the RRA model, vulnerability factors and hazard metrics are used for the estimate of risks and damages related to each receptor, according to the following equations:

$$R_{j,k,s} = f_1 \lfloor E_{k,s}, S_{j,k} \rfloor$$

$R_{j,k,s}$= risk related to the impact k, an exposure $E_{k,s}$ and a susceptibility ($S_{j,k}$);
$E_{k,s}$ = exposure related to the impact k and the scenario s;
$S_{j,k}$ = susceptibility of the receptor j to the impact k.

$$D_{j,k,s} = f_2 \lfloor R_{j,k,s}, Va_{j,k} \rfloor$$

$D_{j,k,s}$= damage related to an impact k, a risk $R_{j,k,s}$ and a Value ($Va_{j,k}$);
$R_{j,k,s}$= risk related to an impact k, an exposure $E_{k,s}$ and a susceptibility ($S_{j,k}$);

$Va_{j,k}$ = environmental or socio-economic value of the receptor j in relation to the impact k.

The exposure function ($E_{k,s}$) is an impact specific function that aggregates $HM_{k,s}$ provided by numerical models for the scenario s and the impact k with $PF_{j,,k}$ associated to the receptor j and the impact k. For impacts affecting the terrestrial environment (e.g., sea level rise inundation, storm surge flooding) the exposure function is used to project the information provided by sea water models inland.

The susceptibility and the value function ($S_{j,k}$ and $Va_{j,k}$) aggregate $SF_{j,k}$ and $VF_{j,k}$ related to the receptor j and the impact k using a specific MCDA function: the Chouquet integral. According to Choquet [1953], the Choquet integral is an aggregation function based on a measure which tries to average the scores given by experts to different coalition of criteria rather than on single criterion scores. The Choquet integral is able to generalize additive operators, such as the ordered weighted average or the weighted mean, and is perfectly suitable in situations where adversarial and synergic effects are present between the criteria to be aggregated.

5. CONCLUSIONS AND REMARKS

DESYCO and the RRA approach are innovative tools to study climate change impacts on coastal zones at the regional scale and support the development of effective adaptation strategies and sustainable Integrated Coastal Zone Management (ICZM), taking into account the increasing issues related to climate change. Regional vulnerability/risk classifications should not attempt to provide absolute predictions about the impacts of climate change. Rather, they should be considered relative indices which provide information about the areas within a region likely to be affected more severely than others.

The originality of our approach consists of the application of a multi-model chain which allows (1) the downscaling of information provided by climate models at the global and sub-continental scale, and (2) the investigation of cascading processes at the regional/local level. This approach also allows the development of a vulnerability assessment procedure that provides a ranking of relative vulnerabilities in the examined coastal territory and allows the identification of the potential for harm from a range of climate related impacts.
Building a multi-model chain requires great initial efforts in terms of time and resources and the tool is applicable only for the study area of concern. However, once set up, a model chain can be improved with other models and used to perform other scenario simulations.
The main issues related to the vulnerability assessment procedure and the construction of vulnerability maps are the diversity of data sources, formats, and spatial scales that introduced geographical errors in the assessment of vulnerability. Moreover, to deal with numerous and heterogeneous data at the regional/local scale increase the geometrical complexity of the analysis and of the results.

Within DESYCO and the developed RRA approach, numerical model simulations used for the construction of climate change scenarios and exposure maps are validated through the comparison with observed data for a control period (Gualdi et al., 2008; Djurdjevic and Rajkovic, 2008). Moreover, the feasibility of the system structure and the efficacy of its interfaces for the final users will be tested through a stakeholder analysis and a questionnaire that will allow to allow the confirmation of the validity of the methodology choices (e.g., the validity of the set of receptors investigated by DESYCO; and the functionalities offered by DESYCO). This will supply some useful contribution to improve the DSS framework.

Finally, the consistency of results provided by DESYCO and the RRA for the case study area will be tested through a sensitivity analysis that allows the ascertainment of how much the uncertainty in the output of the system is influenced by the uncertainty in its input parameters (i.e., scores and weights). This information could be useful for the DSS end users because it explains synthetically how much the assessment of a RRA study is biased by the expert judgements.

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